Necessary but not Sufficient Conditions to Trigger Starbursts

CO and HI Observations of Optically-Selected Interacting Galaxies

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Abstract. We present the analysis of a survey of atomic and molecular gas in interacting and merging galaxies (Horellou & Booth 1997). The sample is optically selected and contains all interacting galaxies (≈ 60 systems) in a well-defined region of the Southern sky (Bergvall 1981). In order to take into account the upper limits due to non-detections, we have carried out a survival analysis. The results are compared with the ones obtained when ignoring the non-detections. We have found evidence for a lower atomic gas content per unit area in interacting galaxies compared to isolated ones. Except for a few systems with high far-infrared luminosity and correspondingly high CO fluxes, the interacting galaxies are not unusually CO-bright. The observed HI-deficiency is therefore not due to a conversion from HI into H_2. Atomic gas from the outer part of the galaxies may have been swept by tidal interaction, or the optical extent of the galaxies may have increased due to the tidal interaction. The interacting galaxies seem to be more efficient at transforming their molecular gas into stars, as indicated by their higher $L_{FIR}/M(H_2)$ ratio. We found no correlation between molecular gas fraction and degree of morphological distortion.

Keywords: galaxies: evolution – galaxies: interactions – galaxies: statistics – ISM: molecules – radiolines: CO and HI lines

1. Introduction

Whereas some kinds of galaxy encounters (merger of two gas-rich galaxies) are believed to lead to substantial gas infall and powerful nuclear starbursts, others seem to have much more subtle consequences for the gas behavior and star-formation properties of the colliders. Most studies to date have focussed on the extreme cases rather than on the interactions themselves, and it is still unclear what the fate of the gas is in galaxies involved in various types and stages of an interaction. In this paper, we study the properties of a complete, optically selected sample of interacting galaxies in which we have searched for both the ^{12}CO(1–0) and the HI lines and estimated the total amounts of molecular and atomic gas (Horellou & Booth 1997). The sample is not biased towards far-infrared (hereafter FIR)-luminous galaxies. It contains all interacting galaxies in a well-defined region of the Southern sky with a blue magnitude brighter than 14.5 ± 0.3 (Bergvall 1981). $UBVRIJHK$ photometry, optical spectra and images have been published (Johansson & Bergvall 1990, Bergvall & Johansson 1995).

Table I. Completeness of the dataset

Parameter	FIR[1]	HI	^{12}CO(1–0)	D_{25}[2]	B magnitudes[2]
Detection rate	38/41	26/48	17/65	48/48	44/55

[1]Three galaxies were detected by IRAS at 60 μm only
[2]Taken from the NASA Extragalactic Database

Table II. Average gas masses and gas surface densities[3]

log M(HI) $M_\odot$	log M(H_2) $M_\odot$	log σ_{HI} $M_\odot$ kpc^{-2}	log σ_{H_2} $M_\odot$ kpc^{-2}
9.69±0.10	9.36±0.18	6.80±0.10	6.37±0.08 (detected)
9.16±0.13	7.85±0.18	6.31±0.10	5.35±0.12 (all)

[3] The diameter used here is D_{25}, the diameter of the blue luminosity at the 25th magnitude per arcsec^2 whereas Haynes & Giovanelli (1984) use UGC diameters: $\log(D_{UGC}+0.3) = 1.0173 \log(D_{25}) + 0.0519$. We quote standard errors, whereas they use standard deviations.

2. CO and HI in an Unbiased Sample

Let us define the gas surface densities as $\sigma_{HI} = M(HI)/D^2$ and $\sigma_{H_2} = M(H_2)/D^2$, where D is the optical diameter of a galaxy. Those are not real surface densities since the atomic gas usually extends beyond the optical disk of a galaxy, whereas the molecular gas as traced by the CO is confined to the inner part of the disk. Nevertheless, although being hybrid quantities, they provide information on *global* galaxy properties and can be compared to the values determined for other samples.

Table 1 describes the completeness of the dataset. In order to take into account the non-detections, we have applied a survival analysis (see Isobe et al. 1986). We have used the Kaplan-Meyer estimator to calculate the average of a dataset containing censored data (upper limits). The mean values of the gas masses in atomic and molecular form are given in Table 2. We list the results obtained for the detected galaxies and those estimated for the whole sample.

2.1. Comparison with Isolated Galaxies

• Interacting Galaxies have less HI per Unit Area

We have compared the HI surface density of the interacting galaxies with those of isolated galaxies observed by Haynes & Giovannelli (1984, hereafter HG84), who have derived a canonical value of 6.81±0.24

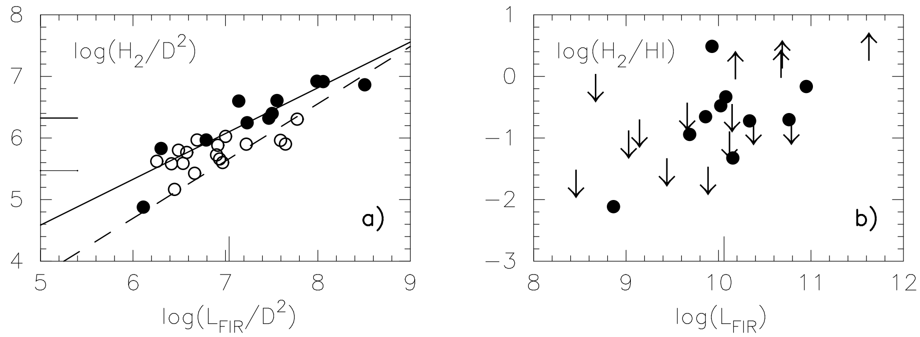

Figure 1. **a)** The H_2 surface density is best correlated with the FIR surface brightness $\sigma_{\rm FIR}$=L_{FIR}/D_{25}^2. The black dots are the CO-detections, the open circles the upper limits. The solid line shows the linear regression to the detected points, whereas the dashed line is the result of the survival analysis. The ticks on the axes show the mean values of the corresponding quantities obtained when ignoring the non-detections and when including them in the survival analysis. **b)** The M(H_2)/M(HI) ratio increases with FIR luminosity. The upwards pointing arrows represent the galaxies for which we have upper limits on the HI mass, whereas the downwards pointing arrows represent those with upper limits on the H_2 mass.

for $\sigma_{\rm HI}$ when averaging over all morphological types. *The interacting galaxies clearly have a lower HI surface density:* 6.33±0.51 for the HI-detected ones, and 6.18 for the whole sample (here we have taken UGC diameters for comparison with HG84 and not D_{25} as in Table II.) The same effect is found when normalizing to the blue luminosity rather than to the optical area.

• An Elevated Star Formation Efficiency

Using observations of isolated galaxies and of galaxies in the outer parts of clusters, Casoli et al. (1998) have established a linear relationship between $\sigma_{\rm H_2}$ and $\sigma_{\rm FIR}$. Their fit is in very good agreement with the one that we obtain for the CO-detected interacting galaxies (solid line in the $\sigma_{\rm H_2}$-$\sigma_{\rm FIR}$ plot displayed on Figure 1a). However, if we include the non-detections in a survival analysis, our fit falls well below the one for isolated galaxies. This means that for the same FIR luminosity, interacting galaxies have less molecular gas. If one interprets the L_{FIR}/M(H_2) ratio as an indicator of the star-formation efficiency (SFE), then *interacting galaxies have a higher SFE compared to isolated galaxies.*

2.2. Molecular Gas Fraction and Strength of Interaction

As pointed out by other authors (e.g., Mirabel & Sanders 1989), we find that the fraction of molecular gas in interacting galaxies increases with the FIR luminosity (Figure 1b). We have searched for relations

between the gas content or tracers of the star formation activity (optical colors, FIR luminosity and dust temperature) and the apparent degree of morphological distortion, using Bergvall's (1981) classification (0: undisturbed; 1: weak; 2: medium; 3: strong). The most strongly disturbed galaxies do not have significantly different optical colors. Their dust temperatures are slightly higher than than those of the less disturbed ones but the difference is at a few σ level.

3. Conclusion

Although all the sample galaxies are in the state of an interaction or even of a merger, their molecular gas fraction and their star-formation activity are not significantly enhanced. This can be understood in the light of recent simulations, which clearly show that the evolution of an interacting system is affected by several factors, such as: the initial conditions (relative mass and morphological types of the colliders), the geometry of the encounter (planar or inclined, prograde or not; e.g., Howard et al. 1993) and the time scale. The amount of molecular gas in particular depends critically on the time, since a starburst of $\simeq 100$ $M_\odot$/yr will exhaust its supply in a few 10^7 yrs. A high concentration of molecular gas will be observable only during that short period. Selecting galaxies on the basis of their emission-line or far-infrared properties introduces a bias toward a particular kind of interaction and/or stage of merger and excludes the more "quiet" collisions.

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